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Improved estimates of population trends of Great Cormorants *Phalacrocorax carbo* in England and Wales for effective management of a protected species at the centre of a human-wildlife conflict

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Capsule A new method of estimating winter Great Cormorant population trends was developed to improve monitoring.

Aims To develop methods of estimating Cormorant population trends with confidence intervals by combining data from different monitoring schemes.

Methods Estimates of inland and coastal winter Cormorant populations were made for England and Wales from 1988 to 2010. Annual counts from the Wetland Bird Survey were used, supplemented with Dispersed Waterbird Survey data for inland populations, and Non-Estuarine Coastal Waterbird Survey data for coastal populations. Bootstrapping was undertaken to produce confidence intervals.

Results The winter Cormorant population in England and Wales increased by *c*. 59% between 1988 and 2010. The population trend of the inland population became less positive from 2004 onwards, the year in which numbers controlled under licence greatly increased.

Conclusions The improved precision of the new estimates provides a sound basis on which to assess potential population-level effects of licensed control of Cormorants. Although there was an indication that recent declines in the inland population were concurrent with increased control intensity, this can only be considered weak evidence, and such effects may be better considered through intensive research on Cormorant site use and dispersal in relation to control activities.

INTRODUCTION

The Great Cormorant *Phalacrocorax carbo* population has grown substantially in Europe over the past few decades (Lindell *et al*. 1995, van Eerden & Gregersen 1995), including a rapid population growth and range expansion in Britain. This has involved both a spread of the continental subspecies *P.c. sinensis* which generally inhabits freshwaters, and an increasing tendency for the coastal breeding *P.c. carbo* to winter inland (Rehfisch *et al*. 1999). The marked population increase of this piscivorous species has resulted in conflicts arising with fishing interests (Feltham *et al*. 1999). Following mounting concerns for economic impacts on commercial inland fisheries, control measures have been implemented in several European countries, including England where, annually since 1996, licences have been granted to shoot limited numbers of birds to control numbers at specific sites, mainly in the winter. Initially, these licences allowed a total of *c*. 500 birds per year to be shot, but in 2004, the upper limit was increased to 3000 individuals in the first few years, and up to 2000 birds annually thereafter (Smith *et al*. 2008). The potential impacts of the intensity of control measures have been assessed by modelling (Central Science Laboratory 2005, Smith *et al*. 2008, but see Green 2008 for a criticism of this work). Monitoring potential impacts of control measures is clearly vital to determine whether they are having desired effects on the population, or if the effects are large enough to have undesirable consequences. For example, the Great Cormorant (hereafter Cormorant) is a feature of several Special Protection Areas (SPAs). Any measure that led to a reduction in numbers on such sites, most importantly below the levels they were at when the site was designated, would contravene the EC Birds Directive (Council Directive 2009/147/EC on the conservation of wild birds) which states that numbers on SPAs should be maintained or improved. Chamberlain *et al*. (in press) found no evidence that local control measures affected year-to-year Cormorant population change at a site level, although there were a number of caveats to this finding, in particular, that the potential effects of disturbance and subsequent dispersal on population change at larger scales than those considered were unknown. The consistency of the results found in Chamberlain *et al*. (in press) have yet to be assessed at a national scale.

Monitoring of Cormorant population trends in England and Wales is largely based on Wetland Bird Survey (WeBS) data. An annual index of the Cormorant population in England and Wales combined has been obtained in the past using the Underhill Indexing Method (Underhill & Prŷs-Jones 1994). There are three main problems with this index. First, it is based on all coastal and inland WeBS sites consistently counted (at least 50% of potential counts undertaken) in England and Wales, whereas it would be informative to produce separate index series for inland and coastal sites because Cormorant-human conflict occurs largely at inland sites. Second, and more importantly, WeBS counts are carried out on sites of variable size and nature. They tend to be coastal sites and larger inland sites, and/or those of particular conservation importance. They often hold large concentrations of waterfowl. However, many Cormorants winter at sites not covered by WeBS, including small waterbodies and watercourses and so it is not known whether population changes at the WeBS sites are representative of those occupied by the Cormorant population as a whole. If they are not, then the population index based solely upon WeBS sites would be biased. The third problem is that the index does not allow accurate estimates of the annual number of Cormorants wintering in England and Wales, nor of the confidence limits around those estimates. The absolute number, rather than an index, is needed because when modelling the response of the population to licensed control it is necessary to know the number of Cormorants killed as a proportion of the total population. Although the population index has previously been converted to a series of population estimates (Smith *et al*. 2008), this was done without allowing for potential bias in population changes between WeBS and non-WeBS sites (see above).

It is very important for policy makers and managers that estimates of population trends are trustworthy and as accurate as possible, especially when the species is exposed to management.

Therefore, it is highly relevant to use data in the best possible way and develop methods that can reduce the confidence intervals. This paper addresses this issue by constructing a time series of estimates of the England and Wales wintering Cormorant population, adjusted for the unrepresentative coverage of inland wetlands by WeBS, that will better inform assessments of the efficacy and impact of licensed control of Cormorants. The models currently used for this purpose utilise population series based upon the unadjusted WeBS index (Smith *et al.* 2008, see also Green 2008). In addition, we also provide new estimates of the coastal and total populations of Cormorant for England and Wales, by combining WeBS core counts from coastal sites and NEWS data. Finally, we assess the extent to which the introduction of control measures has coincided with changes in the rate of Cormorant population growth based on the improved trends derived. These analyses add considerably to our understanding of trends in the Cormorant population of England and Wales and therefore will allow more accurate monitoring of the population and of impacts of control measures.

METHODS

Bird survey methods

Cormorant population trends were estimated by combining data from three separate surveys undertaken to monitor waterbirds in winter: the Wetland Bird Survey (WeBS Pollitt *et al*. 2003), the Dispersed Waterbirds Survey (DWS; Jackson *et al*. 2006) and the Non-Estuarine Coastal Waterbird Survey (NEWS; Rehfisch *et al*. 2003). A summary of the sample sizes and years covered by each survey is given in Table 1. Detailed methods for the three surveys have been published elsewhere, so we provide only brief summaries here. WeBS Core Counts are made by observers undertaking a monthly count of all waterbird species (as defined by Wetlands International - Rose & Scott 1997) in a predefined area (the WeBS site). WeBS sites are selected by observers, although co-ordination of the scheme ensures that these sites cover the vast majority of estuaries and large water bodies in England and Wales, in addition to many smaller sites. Counts are undertaken on predetermined priority dates which enables synchronization across the whole country, thus reducing the likelihood of birds being double counted or missed. For this analysis, the annual site-level winter Cormorant population size (henceforth referred to as Cormorant count) was taken as the maximum monthly total from the December to February counts, the period over which annual population indices are calculated. Maximum count was chosen to be consistent with the approach used for SPA site designation (Stroud *et al*. 2001), although maximum count is very closely related to average count per site per winter (Chamberlain *et al*. in press).

The Dispersed Waterbird Survey (DWS) was designed in part to address the potential bias caused by the non-random selection of WeBS sites, in addition to estimating waterbird populations across the wider countryside (Jackson *et al*. 2006). The DWS was conducted in one winter (2002/03) at a random sample of inland 1-km Ordnance Survey grid squares which were allocated to volunteer observers derived from a random sample stratified by cover of freshwater, and by upland or lowland land class. Observers made a single timed visit of at least two hours' duration to each 1-km square during the winter of 2002/03, during which they counted all waterbirds seen. Only squares with near-complete coverage (a minimum of 90% of the square accessible) were included in analyses.

The Non-Estuarine Coastal Waterbird Survey (NEWS) aims to supplement the Wetland Bird Survey (WeBS) Core Counts by providing data for non-estuarine coasts for which WeBS Core Counts obtain incomplete coverage (Rehfisch *et al.* 2003). Unlike DWS, NEWS aims for as complete survey coverage as possible (i.e. ideally the whole length of the UK's non-estuarine coastline), rather than a random sample, although this was not always possible due to accessibility (i.e. inaccessible terrain or private land with no public access). Surveys were undertaken in 1997/98 and 2006/07 (the forerunner of NEWS, the Winter Shorebird Count undertaken in 1985, did not include Cormorants and so is not considered here). Coastal UK was divided into survey sections (usually a maximum of 5km in length). Birds on each count section were counted once per winter, within a 7-hour period starting 3.5 hours before low water and finishing 3.5 hours after low water. Birds located on the intertidal shore, at sea and on adjacent areas inland (defined as within 100 m of the high water mark) were recorded separately.

Inland trends

Inland trends were derived by combining observed annual Cormorant count from Wetland Bird Survey (WeBS) sites with modelled annual estimates based on Dispersed Waterbird Survey (DWS) data. WeBS Core data were used to calculate the maximum Cormorant count per winter (Dec-Feb inclusive) per site from 1988 to 2010 (NB henceforth 'year' refers to the December of a given calendar year according to WeBS convention, so 2010 signifies winter 2010/11). Each site was assigned to categories of urban habitat cover and water cover (for each cover type, high > 5ha/km^2, medium 0.1 to 5 ha/km^2, low < 0.1 ha/km^2), habitat class (upland or lowland) and region (East and West Midlands were combined into midlands, and Yorkshire and North East were combined into northeast, due to low sample sizes), using the principal 1-km squares of each WeBS site. Hence, for large sites, it was assumed that the habitat categories of the principal 1-km were representative of the site as a whole. Only WeBS sites from inland parts of England and Wales were included. Coastal sites were avoided by deleting sites clipped by a 1-km coastal buffer.

Data from the Dispersed Waterbird Survey were used to model inland population estimates from non-WeBS 1-km squares in relation to habitat covariates. Maximum Cormorant count per square for winter 2002 was calculated. Squares with <90% survey coverage were omitted. Region, habitat codes and coastal squares were treated as for the analysis of WeBS data. Squares that included a WeBS site (or part of a WeBS site) were omitted. The final sample was 339 1-km squares. Cormorant count was modelled using a negative binomial error term and a logarithmic link with PROC GENMOD in SAS. Parameter estimates from this model were then used in conjunction with habitat data to predict Cormorant counts for every inland 1-km square in England and Wales that did not contain a WeBS site.

Estimates of year-to-year change in the wider (i.e. non-WeBS) inland Cormorant population were made by analysing WeBS data using the modelling approach of Freeman and Newson (2008), henceforth referred to as F&N. Parameter estimates derived from F&N were then applied to estimated counts for the wider countryside from the DWS model (see above) to extrapolate annual trends for each 1-km square in each year. The F&N approach has been described in detail elsewhere (e.g. Freeman & Newson 2008, Newson *et al*. 2012, Chamberlain *et al*. in press) and thus only a summary is provided here. The F&N approach resembles previous methods in using Poisson regression with a logarithmic link and with the count in year t as the dependent variable. However, it provides a more efficient way of modelling time-series count data than the previous methods. Previously, the count in year t was modelled with the log of the count in the previous year t-1 as an offset (e.g. Thomson *et al*. 1998). This is equivalent to modelling the log of the rate of year-to-year change r_t as a linear function of covariates. This method has several disadvantages including the need to exclude years in which the count in the previous years is zero and all years in which a count was missing for either the year itself or the previous year. The F&N method allows the analysis of all counts in a series with missing data and zero counts and also is able to include the first year of a time-series; it was applied using a mixed effects Poisson model fitted in R using glmmPQL, specifying site as a random effect, and analysing maximum count in relation to urban cover, water cover and habitat class as fixed effects. The analysis results in estimates of year-to-year change (r_1 to r_{23} for 24 years' data) and estimates of the effects of the habitat covariates on the rate of change. These estimates were then used in conjunction with DWS to derive estimated annual Cormorant totals for every 1-km square in England and Wales (see below).

Predicted Dispersed Waterbird Survey (DWS) counts for each square from 2002 from the negative binomial model (see above) were used as a baseline to predict year-to-year change using estimates from the F&N model. For each grid square, an estimate of year-to-year change was made by summing parameter estimates from the F&N model (urban + water + habitatclass + region + intercept + year), where year is the estimated rate of change r_1 to r_{23}. This was done by standardising estimates relative to 2002, i.e. the (untransformed) estimate for 2002 was subtracted from other estimates, meaning that for 2002 it was zero. For each square in each year, the predicted count was (DWS predicted count) * (exp(estimate)). The final output was therefore an estimate of Cormorant abundance for each inland 1-km square (not including WeBS sites) from 1988 to 2010. The annual estimate of total inland population was therefore these model-derived estimates added to the observed maximum counts for inland WeBS sites.

Confidence intervals were fitted to the above trends using bootstrapping. WeBS data were bootstrapped by randomly resampling (with replacement) from the dataset 119 times for each region in each year (i.e. a random data set was created, randomly sampling from a given region and up to the same sample size as that region/year). For each bootstrap replicate, the F&N model was run to output parameter estimates for the model of year-to-year change.

Dispersed Waterbird Survey (DWS) data were bootstrapped by randomly resampling (with replacement) from the dataset of 1-km squares for each region as above. A model was then run on each bootstrap sample to produce estimates (per region) for all non-WeBS inland 1-km squares in England, using the same approach as previously (i.e. a negative binomial model). For each run of the bootstrap, annual totals were extrapolated using the F&N parameter estimates for the equivalently numbered bootstrap of the WeBS data, as outlined previously.

Generalized additive models (GAMs; Hastie & Tibshirani 1990) were used to determine smoothed WeBS population trends. GAMs provide a complete modelling framework in which the smoothed abundance indices are made fully within the context of the original model (Fewster *et al*. 2000). Consequently, the use of GAMs have become the *de facto* means of reporting WeBS waterbird trends (Atkinson *et al*. 2006). A GAM was run on the total WeBS count per year for inland sites. The Dispersed Waterbird Survey estimates for all inland 1-km squares in England and Wales without a WeBS site, derived from bootstrapping, were added to the GAM annual estimate for all inland WeBS sites to give total annual estimates of inland Cormorants for each bootstrap replicate. The bootstrap estimates for a given year were ranked and the bounds of the central 95% of estimates taken as upper and lower 95% confidence limits.

Coastal trends

Coastal trends were calculated by combining data from Wetland Bird Survey (WeBS) coastal sites and the Non-Estuarine Coastal Waterbird Survey (NEWS) survey sections in a process similar to that used for inland trends (i.e. observed WeBS counts plus modelled estimates from NEWS). Maximum counts per winter were calculated for WeBS coastal sites (i.e. those which were clipped by a 1-km coastal buffer) from 1988 to 2010. For a national population estimate, these counts were combined with NEWS data. NEWS data were extracted for sections in England and Wales that were counted for Cormorants in the survey in 1997 and 2006. This did not include estuaries, which are covered under WeBS. Sections of coastline surveyed in NEWS were included with at least one of the three habitats covered (i.e. sea, intertidal and inland), thus it is assumed that habitats not covered by the survey were unsuitable and therefore that the count in them was zero. Totals per region and year were calculated. There was c. 10% of suitable coastline that was not surveyed in either year. This was corrected for in the population estimates by taking the mean Cormorant density per km of coastline for each region, and applying this mean to the uncounted coastline. These additional estimates were then added to the observed totals.

For annual totals, parameter estimates were used from F&N run on coastal WeBS data analogous to the approach used for inland sites (see above), but using only year-to-year change and region (Dispersed Waterbird Survey habitat codes were not available for most coastal squares). The Non-Estuarine Coastal Waterbird Survey sections were either surveyed only once, either in 1997 or 2006, or in both years. In order to construct a time series, annual estimates from F&N were derived for different groups: 1997 only, 2006 only, 1997 both and 2006 both (using the appropriate corresponding WeBS year as the reference year), also including estimates of unsurveyed coastline. A mean of the annual estimates for sections that were covered in both years was calculated and added to the annual estimates from 1997 and 2006. Non-Estuarine Coastal Waterbird Survey annual totals plus WeBS annual totals were then summed to produce the coastal population trend.

WeBS data for coastal sites were bootstrapped as above, and F&N parameters were output for each bootstrap. Non-Estuarine Coastal Waterbird Survey (NEWS) data were bootstrapped by selecting sections at random for a given year (1998 or 2007) and region so the total length of sections was approximately (usually within *c*. 1 km) the same as that covered in the actual survey. The counts from these random sections were summed to give a regional and year estimate for each bootstrap replicate. These bootstrap estimates were then used in conjunction with parameter estimates from the coastal F&N models to extrapolate annual totals, as described for the observed NEWS data. NEWS estimates were added to an annual estimate for WeBS coastal sites derived from a GAM (as for the inland sites – see above), and confidence intervals were calculated based on this sample of bootstrap replicates.

Combined trends

Annual population estimates were simply the sum of coastal and inland estimates for each year. Confidence intervals were calculated as the 95% confidence limits of the sum of coastal and inland bootstrap estimates for each year.

Population change in relation to control measures

The extent of population change was determined for different periods of the whole time series defined according to the introduction of significant changes made to the licensing policy (2004) when the maximum number that could be controlled increased substantially. The change in the rate of Cormorant population growth for England only (where licensed control took place) between the period before elevated control levels began in the 2004-2005 winter and the period since then was tested statistically by fitting a piecewise ordinary least squares regression relating the natural logarithm of the population size to year. The slope of the regression was assumed to change in 2004. The statistical significance of the change in slope between the two periods 1988-2004 and 2004-2010 was tested using an F test in which the residual sums of squares of the piecewise model was compared with that for the simpler model with one slope covering the whole period 1988-2010. Because culling is restricted to inland areas, the analysis was performed for both the inland and inland-coastal combined estimates.

RESULTS

The parameter estimates for effects of urban land cover class, water cover class, upland/lowland cover class and region on year-to-year change in Cormorant count on inland Wetland Bird Survey (WeBS) sites in England and Wales derived from the Freeman and Newson (2008) (F&N) model are shown in Table 2 (parameter estimates for year-to-year change are given in Appendix 1). Population growth rates were significantly greater in more urbanised areas, at sites with smaller water bodies and in most regions away from the east and south-east of England. Lowland sites also showed a significantly higher population growth rate than upland sites, but it should be noted that there were very few records in upland areas. Cormorant count from 2002 from Dispersed Waterbird Survey (DWS) data was modelled in relation to the same categorical variables as were used in the F&N analysis (Table 3). There was no significant difference between urban land cover classes, nor between regions (and note that sample size was small and no Cormorants were recorded for the London region). Estimates of Cormorant count were significantly lower in squares with low water cover, and also in upland squares where there were very few records. The results from the analysis of year-to-year change on coastal WeBS sites in England and Wales are shown in Table 4 (parameter estimates for year-to-year change are given in Appendix 1). Most regions had experienced significantly greater population growth compared to East Anglia, which again probably represents greater population growth and range expansion away from eastern England.

Estimates of annual Cormorant population size with confidence limits, for non-coastal sites, coastal sites and all sites combined in England and Wales derived from WeBS, DWS and Non-Estuarine Coastal Waterbird Survey (NEWS) data over all years for 1988 to 2010 are given in Figure 1. Populations inland increased in the earlier part of the survey period, but became more stable after the late 1990s, although the confidence intervals were fairly wide (Fig. 1a). Coastal trends showed a clearer pattern of increase over a longer series of years (Fig. 1b), though with some marked fluctuations, and had very narrow confidence intervals, because a very large proportion of the coast was surveyed. Combined trends showed a general overall increase (Fig. 1c) until about 2004.

For the inland population, there was an indication that the population trend differed between the two periods. The regression slope for 1988-2004 was 0.016 (i.e. an exponential population growth rate of 1.6% per year). The regression slope for 2004 – 2010, the period of the increased control, was -0.013 (an exponential population decline rate of 1.3% per year). The fitted value for the intercept was 9.336 (1987 being coded as equal to 1). An F test indicated that the population trend had become less positive since the increased levels of licensed control was introduced, although the result was not quite significant ($F_{1,20}$ = 4.02, P = 0.058).

For the combined inland and coastal population, trends were more similar and positive before and after 2004. The regression slope for 1988-2004 was 0.017 (an exponential population growth rate of 1.7% per year). The regression slope for 2004 – 2010, the period of increased control, was 0.001 (an exponential population growth rate of 0.1% per year). The fitted value for the intercept was 9.73. An F test indicated that there was no significant difference in population trend since the increase in licensed control was introduced ($F_{1,20}$ = 1.45, P = 0.24).

DISCUSSION

The previous estimate of Cormorant winter population size based on Wetland Bird Survey (WeBS) and Dispersed Waterbird Survey (DWS) data for Great Britain was 30 697 birds (95% confidence limits 20 840 to 46 034) in 2002 (Jackson *et al*. 2006). Smith *et al*. (2008) estimated the English population as 75% of this, a total of 23 032, in 2002. The updated estimate for England calculated here for 2002 was similar at 21005 birds, although the confidence in this new estimate is higher with a much narrower confidence interval (7 139 compared to 18 896). A comparison of the annual estimates presented in Smith *et al*. (2008), up to 2002, show close similarity in fluctuations with the new estimates and those from the previous method (Fig. 2). The year-to-year change (i.e. population in year t/population in year t-1) was highly correlated (r_{13} = 0.78, P < 0.001), suggesting that the new method would have little influence on consideration of the direction of change. However, there were some important differences in the estimated magnitude of change, which were generally lower using the new method (by 8.5% per year on average compared to the previous estimate), especially in the later part of the period considered. Therefore, in terms of overall trend, the new method has not altered previous conclusions about the direction of population growth in the winter Cormorant population. However, a key improvement of the method developed here is the marked narrowing of the confidence intervals and hence the improved ability of detecting population change, which is crucial in assessing impacts of control measures. Furthermore, although the differences in the magnitude of population estimates were relatively small, in terms of policy it is very important to have as accurate an estimate as possible, because the data are used for deciding the upper limit for annual control.

The overall winter population of Cormorants in England and Wales increased by an estimated 59% between 1988 and 2010, and similar increases have been evident for both coastal and inland populations (Fig. 1). Analysis of growth rates indicated that the population has expanded westward and northward in England and into Wales, and into more urbanized areas and areas with smaller water bodies, over this period. Much of the population growth was however in the earlier part of the period, particularly for the inland population which had apparently levelled out somewhat since the mid-1990s. Both coastal and inland populations have decreased slightly since *c*. 2004.

Patterns of change in relation to periods defined according to the change in licensed control indicated that the inland population trend of Cormorants wintering in England has become less positive since the number of birds killed under licence was increased. A greater effect may be expected inland because the majority of control measures are carried out on inland water bodies (Natural England unpubl. data). However, other factors may have been important in influencing overall population trends. Winter severity has been shown to be linked to adult Cormorant mortality rates (Frederiksen & Bregnballe 2000), therefore harsh winters may be associated with population declines. This seems unlikely for the most recent changes, at least on a national scale, because the mean winter temperature for England for 2001 to 2005 was higher than the long-term average (www.metoffice.gov.uk). Low winter temperatures may, however, have been a contributory factor to the low numbers in 1997 which followed the relatively cold winter in 1996. A further factor is that the carrying capacity of available habitat for the population may have been reached or approached.

If so, population growth rates might slow because of competition for resources. However, with the data available it is not possible to disentangle effects of density-dependent competition, increased mortality through licensed shooting and other factors such as weather.

Chamberlain *et al*. (in press) found no negative effect of control intensity (the proportion of the local population reported killed) in the surrounding area on year-to-year change in Cormorant numbers on inland WeBS sites, and indeed several results suggested positive effects. The fine-scale results therefore apparently contradict those presented here for the national (i.e. English) level, where a decline in growth rate followed the introduction of more intensive control measures. Although strongly indicative of a lack of effect at smaller scales (within a 5km radius of a given site), the results of Chamberlain *et al*. (in press) were less convincing at larger scales due to smaller sample sizes caused by missing or inadequate control data. Wider dispersal induced by disturbance could be an important effect of control measures which could lower the chances of detection of effects at relatively small scales, and which may also explain some of the apparent positive relationships observed at small scales (Chamberlain *et al*. in press). Clearly reconciling these apparently diverse results at different scales (national and local) should be a priority. In addition to collecting additional Cormorant data, including more intensive research of site use and movement in relation to control measures (Chamberlain *et al*. in press), a more comprehensive and detailed data base on site-level control effort is required.

The analyses presented here have drawn together several different data sets in order to give the most complete assessment to date of Cormorant population trends in England and Wales. In combining these data sets, sometimes using a modelling approach, we make a number of assumptions. Most importantly, we have assumed that we are able to estimate Cormorant count for the whole of England and Wales, outside of Wetland Bird Survey (WeBS) sites, based on Dispersed Waterbird Survey (DWS) and Non-Estuarine Coastal Waterbird Survey (NEWS) data. For DWS at least, these data should be broadly representative because sites were selected using a random stratified approach in order that they were representative of land use types (Jackson *et al*. 2006). The surveys were, however, taken from only one (DWS) or two (NEWS) winters. In applying estimates of year-to-year change from the WeBS data to the DWS and NEWS data, the assumptions are made that trends over time will be equal across the different data sets, and across different land use types within DWS or NEWS, i.e. there will be no year x survey interaction, and no year x land use type interaction. Repeated surveys of both DWS and NEWS in the future will enable a formal test of these assumptions and hence should improve our ability to monitor winter Cormorant populations and hence potential impacts of control measures.

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REFERENCES

Atkinson P.W., Austin, G.E., Rehfisch, M.M., Baker, H., Cranswick, P., Kershaw, M., Robinson, J., Langston, R.H.W., Stroud, D.A., van Turnhout, C. & Maclean, I.M.D. 2006. Identifying declines in waterbirds: the effects of missing data, population variability and count period on the interpretation of long-term survey data. *Biol. Conserv.* **130**: 549-559.

Chamberlain, D.E., Austin, G.E., Newson, S.E., Johnston, A. & Burton N.H.K. in press. Licensed control does not reduce local Cormorant *Phalacrocorax carbo* population size in winter. *J. Orn*.

Feltham, M.J., Davis, J.M., Wilson, B.R., Holden, T., Cox, I.G., Harvey, J.P. & Britton, J.R. 1999. *Case Studies of the Impact of Fish-eating Birds on Inland Fisheries in England and Wales*. Ministry of Agriculture, Fisheries and Food, London.

Fewster, R.M., Buckland, S.T., Siriwardena, G.M., Baillie, S.R., Wilson, J.D. 2000. Analysis of population trends for farmland birds using generalized additive models. *Ecology* **81**: 1970–1984.

Frederiksen, M. & Bregnballe, T. 2000. Evidence for density-dependent survival in adult cormorants from a combined analysis of recoveries and resightings. *J. Appl. Ecol.* **69:** 737-752.

Freeman, S.N. & Newson, S.E. 2008. On a log-linear approach to detecting ecological interactions in monitored populations. *Ibis* **150:** 250-258.

Green, R.G. 2008. Assessing the impact of culling on population size in the presence of uncertain density dependence: lessons from a great cormorant population. *J. Appl. Ecol.* **45**: 1683–1688.

Hastie, T.J. & Tibshirani, R.J. 1990. *Generalized Additive Models*. Chapman & Hall, London.

Jackson, S.F., Austin, G.E. & Armitage, M.J.S. 2006. Surveying waterbirds away from major waterbodies: implications for waterbird population estimates in Great Britain. *Bird Study* **53:** 105-111.

Lindell, L., Mellin, M., Musil, P., Przybysz, J. & Zimmerman, H. 1995. Status and population development of breeding Cormorants *Phalacrocorax carbo sinensis* of the central European flyway. Ardea **83**: 81-92.

Newson, S.E., Johnston, A., Renwick, A.R., Baillie, S.R. & Fuller, R.J. 2012 Modelling large-scale relationships between changes in woodland deer and bird populations. *J. Appl. Ecol*. **49**: 278–286.

Pollitt, M.S., Hall, C., Holloway, S.J., Hearn, R.D., Marshall, P.E., Musgrove, A.J., Robinson, J.A. & Cranswick, P.A. 2003. *The Wetland Bird Survey 2000–01: Wildfowl and Wader Counts*. BTO/WWT/RSPB/JNCC, Slimbridge.

Rehfisch, M.M., Wernham, C.V. & Marchant, J.H. 1999. *Population, Distribution, Movements and Survival of Fish-eating Birds in Great Britain.* DETR, London

Rehfisch, M.M., Holloway, S.J. & Austin, G.E. 2003. Population estimates of waders on the non-estuarine coasts of the UK and Isle of Man during the winter of 1997–98. Bird Study **50:** 22–32.

Smith, G.C., Parrot, D. & Robertson, P.A. 2008. Managing wildlife populations with uncertainty: Cormorants *Phalacrocorax carbo. J. Appl. Ecol.* **45**: 1675–1682.

Stroud, D.A., Chambers, D., Cook, S., Buxton, N., Fraser, B., Clement, P., Lewis, P., McLean, I., Baker, H. & Whitehead, S. 2001 *The UK SPA network: its scope and content.* Peterborough, JNCC

Thomson, D.L., Green, R.E., Gregory, R.D. & Baillie, S.R. 1998. The widespread declines of songbirds in rural Britain do not correlate with the spread of their avian predators. *Proc. Royal Soc. B* **265:** 2057-2062

Underhill, L.G. & Prŷs-Jones, R. 1994 Index numbers for waterbird populations. I. Review and methodology. *J. Appl. Ecol.* **31:** 463-480.

Van Eerden, M.R. & Gregersen, J. 1995 Long-term changes in the north-west European population of Cormorants *Phalarocorax carbo sinensis*. *Ardea* **83**: 61-79

Table 1. Summary of data set sample sizes and the number of years covered in the analysis.

Survey	**Unit**	**Years**	$\mathbf{N_{mean}}$	$\mathbf{N_{min}}$	$\mathbf{N_{max}}$	$\mathbf{N_{total}}$
WeBS inland	Site	24	731 ± 13	585	811	1445
WeBS coastal	Site	24	107 ± 3	76	126	220
WeBS total	Site	24	838 ± 15	664	937	1665
DWS	Square	1	n/a	n/a	n/a	339
NEWS	Section	2	997 ± 123	874	1120	1331

Unit refers to the name of the sampling unit for each survey as referred to in the text. N_{mean} is the mean ± se number of survey units per year, N_{min} and N_{max} are respectively the minimum and maximum number of units surveyed in any one year, N_{total} is the number of unique units surveyed over all years, n/a indicates a survey carried out in only one winter.

Table 2. Estimates and standard errors of the log-ratio of year-to-year change of maximum winter Cormorant count on inland WeBS sites in England and Wales derived from a Freeman and Newson (2008) model.

Parameter	Level	Estimate	Se	P
Urban	Low	-0.003	0.003	0.33
	Medium	-0.009	0.003	<0.001
Water	Low	0.012	0.002	<0.001
	Medium	0.025	0.003	<0.001
Habitat class	Lowland	0.024	0.005	<0.001
Region	London	0.019	0.006	0.001
	Southeast	0.001	0.004	0.88
	Southwest	0.019	0.004	<0.001
	Northeast	0.023	0.005	<0.001
	Northwest	-0.021	0.003	<0.001
	Midlands	-0.002	0.004	0.54
	Wales	-0.024	0.008	0.002
Intercept		0.268	0.052	<0.001

Estimates are presented for urban habitat category, water cover category ('high' is the reference category for both, with Parameter = 0), habitat class ('Upland' reference category), and region (East Anglia reference category). Year-to-year change estimates are given in Appendix 1. Site was fitted as a random effect (sd = 2.53) and Poisson errors were specified. N = 17522 observations from 1445 sites.

Table 3. Estimates and standard errors of winter Cormorant count on inland 1-km squares on Dispersed Waterbird Survey sites in England and Wales.

Parameter	Level	Estimate	se	P
Urban	Low	0.043	1.183	0.97
	Medium	-0.606	1.324	0.65
Water	Low	-3.728	1.178	0.002
	Medium	0.001	1.305	0.99
Habitat class	Lowland	25.834	0.000	<.0001
Region	London	-23.617	153129	0.99
	Midlands	-2.386	1.572	0.13
	Northeast	-0.673	1.385	0.63
	Northwest	0.858	1.415	0.55
	Southeast	0.270	0.682	0.69
	Southwest	-0.566	1.009	0.58
	Wales	-1.925	1.162	0.10
Intercept		-25.110	1.305	<.0001

Estimates are presented for urban habitat category, water cover category ('high' is the reference category for both, with Parameter = 0), habitat class ('Upland' reference category), and region (East Anglia reference category), derived from a negative binomial model. n = 339 sites.

Table 4. Estimates and standard errors of the log-ratio of year-to-year change of maximum winter Cormorant count on coastal WeBS sites in England and Wales derived from a Freeman and Newson (2008)model.

Parameter	**Level**	**Estimate**	**Se**	**P**
Region	London	0.012	0.011	0.30
	Southeast	0.059	0.005	<0.001
	Southwest	0.045	0.012	<0.001
	Northeast	0.010	0.014	0.50
	Northwest	0.058	0.014	<0.001
	Midlands	0.054	0.008	<0.001
	Wales	0.071	0.009	<0.001
Intercept		0.865	0.140	<0.001

Estimates are presented for region (East Anglia reference category). Year-to-year change estimates are given in Appendix 1. Site was fitted as a random effect (sd = 2.82) and Poisson errors were specified. N = 2560 observations from 220 sites.

Appendix 1. Full model details

Table A1. Estimates and se of year-to-year change of maximum winter Cormorant count on (a) inland WeBS sites in England and Wales derived from a Freeman and Newson (2008) (F&N) model, and (b) coastal WeBS sites in England and Wales derived from a F&N model. Year-to-year change estimates are given by r_1-r_{23}, where r_1 is the change from 1987 to 1988. Other details as Table 2.

(a) Inland

Parameter	Level	Estimate	se	P
Annual change	r_1	0.135	0.016	<0.001
	r_2	0.247	0.015	<0.001
	r_3	0.056	0.014	<0.001
	r_4	-0.058	0.014	<0.001
	r_5	0.139	0.014	<0.001
	r_6	-0.082	0.014	<0.001
	r_7	0.083	0.014	<0.001
	r_8	0.131	0.013	<0.001
	r_9	-0.080	0.013	<0.001
	r_{10}	-0.156	0.014	<0.001
	r_{11}	0.079	0.014	<0.001
	r_{12}	-0.026	0.014	0.062
	r_{13}	-0.047	0.014	0.001
	r_{14}	0.156	0.028	<0.001
	r_{15}	-0.007	0.028	0.80
	r_{16}	0.001	0.013	0.92
	r_{17}	-0.087	0.014	<0.001
	r_{18}	-0.033	0.014	0.018
	r_{19}	-0.030	0.014	0.035
	r_{20}	0.037	0.014	0.010
	r_{21}	-0.002	0.014	0.88

	r_{22}	-0.114	0.014	<0.001
	r_{23}	0.042	0.015	0.004

(b) Coastal

Parameter	**Level**	**Estimate**	**se**	**P**
Annual change	r_1	0.047	0.112	0.67
	r_2	0.094	0.105	0.37
	r_3	0.059	0.098	0.55
	r_4	-0.072	0.097	0.46
	r_5	-0.006	0.100	0.95
	r_6	0.193	0.094	0.041
	r_7	-0.025	0.088	0.78
	r_8	0.068	0.087	0.44
	r_9	-0.156	0.088	0.077
	r_{10}	-0.079	0.092	0.34
	r_{11}	-0.055	0.093	0.56
	r_{12}	0.149	0.089	0.095
	r_{13}	-0.479	0.096	<0.001
	r_{14}	0.568	0.093	<0.001
	r_{15}	-0.460	0.090	<0.001
	r_{16}	0.427	0.089	<0.001
	r_{17}	-0.119	0.080	0.14
	r_{18}	-0.321	0.088	<0.001
	r_{19}	0.102	0.090	0.26
	r_{20}	-0.050	0.088	0.57
	r_{21}	0.121	0.086	0.16
	r_{22}	-0.206	0.086	0.016
	r_{23}	0.152	0.086	0.076

Figure legends

Figure 1. Annual estimates of winter Cormorant population in England and Wales, for inland sites (a), coastal sites (b) and all sites (c). Dashed lines are upper and lower 95% confidence limits. Note that year refers to the December of a given winter (e.g. 2000 indicates winter 2000/01).

Figure 2. Estimates of annual Cormorant winter population size in England based on the methods presented in this paper, and on the methods of Smith *et al*. (2008).

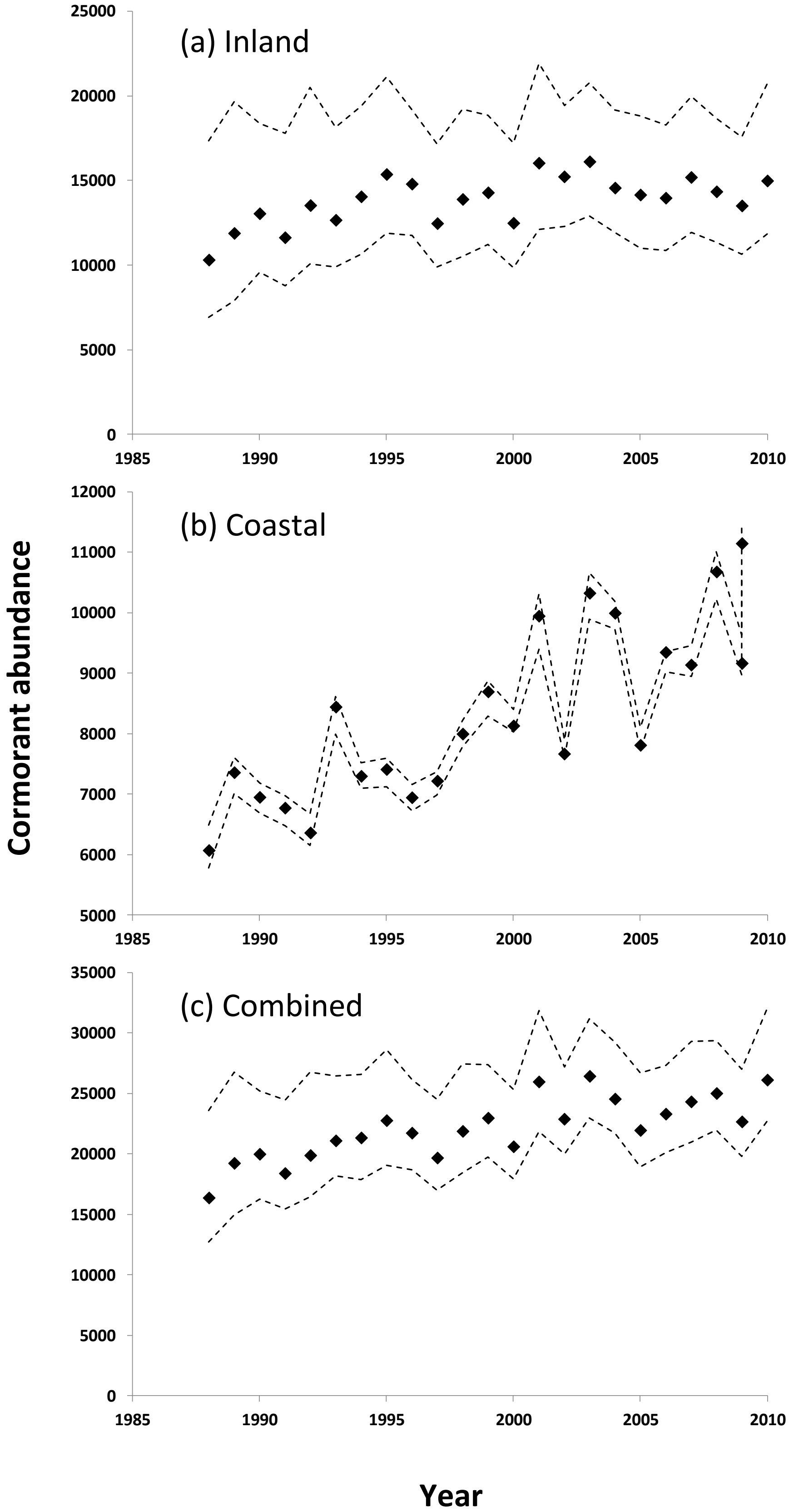
(a) Inland
(b) Coastal
(c) Combined
Cormorant abundance
Year
0
5000
10000
15000
20000
25000
30000
35000
6000
7000
8000
9000
11000
12000
1985
1990
1995
2000
2005
2010

Fig. 1

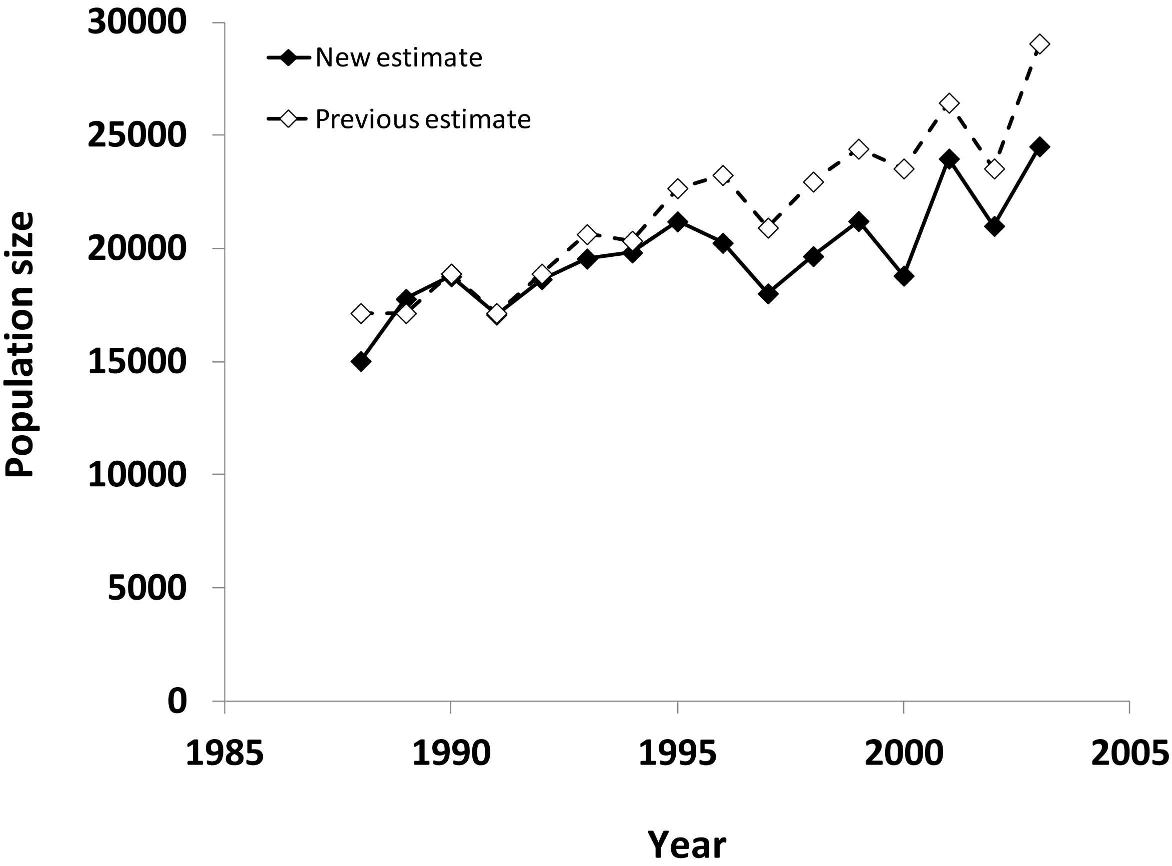
30000
25000
20000
15000
10000
5000
0
Population size
New estimate
Previous estimate
1985
1990
1995
2000
2005
Year

Fig. 2